

Concentrations and Assembly Histories of Dark Matter Halos

R. H. WECHSLER^{1,2}, J. S. BULLOCK³, J. R. PRIMACK¹, A. V. KRAVTSOV^{3,4}, & A. DEKEL⁵

¹*Physics Department, University of California, Santa Cruz, CA, 95064*

²*Physics Department, University of Michigan, Ann Arbor, MI 48109*

³*Department of Astronomy, The Ohio State University, Columbus, OH 43210*

⁴*Hubble Fellow*

⁵*Racah Institute of Physics, The Hebrew University, Jerusalem 91904 Israel*

Abstract. We study the relation between the density profiles of dark matter halos and their mass assembly histories, using a statistical sample of halos in a high-resolution N-body simulation of the Λ CDM cosmology. For each halo at $z = 0$, we identify its merger-history tree, and determine concentration parameters c_{vir} for all progenitors, thus providing a structural merger tree for each halo. We fit the mass accretion histories by a universal function with one parameter, the formation epoch a_c , defined when the log mass accretion rate $d \log M / d \log a$ falls below a critical value. We find that late forming galaxies tend to be less concentrated, such that c_{vir} “observed” at any epoch a_o is strongly correlated with a_c via $c_{\text{vir}} = c_1 a_o / a_c$. Scatter about this relation is mostly due to measurement errors in c_{vir} and a_c , implying that the actual spread in c_{vir} for halos of a given mass can be mostly attributed to scatter in a_c . Because of the direct connection between halo concentration and velocity rotation curves, and because of probable connections between halo mass assembly history and star formation history, the tight correlation between these properties provides an essential new ingredient for galaxy formation modeling.

1 METHOD

We investigate the connection between halo density profiles and their mass assembly histories, using a structural merger tree constructed from a high-resolution N-body simulation of a flat Λ CDM model with $\Omega_m = 0.3$, $h = 0.7$ and $\sigma_8 = 1.0$, whose evolution has been simulated with the ART code [2]. The trajectories of 256^3 cold dark matter particles are followed within a cubic, periodic box of comoving size $60h^{-1}\text{Mpc}$ from redshift $z = 40$ to the present. We use distinct halo catalogs at 36 output times spaced between $z = 7$ and 0. NFW density profiles [3], $\rho_{\text{NFW}}(r) = \rho_s / [(r/R_s)(1 + r/R_s)^2]$, are measured for each halo with more than 200 particles, corresponding to halos more massive than $2.2 \times 10^{11} h^{-1} M_\odot$. For each halo at $z = 0$, we identify its full merger history, and determine concentration parameters $c_{\text{vir}} \equiv R_{\text{vir}}/R_s$ for all progenitors, thus providing a structural merger tree for each of ~ 3000 halos.

2 RESULTS

Figure 1 (left) shows the history of mass growth for the major progenitors of several different halos, spanning a range of masses and concentration parameters. Massive halos tend show substantial mass accumulation up to late times, while the growth curves for less massive halos tend to flatten out earlier. By examining a range of full mass assembly histories for our sample of halos, we find that both average mass accretion histories and mass accretion histories for individual halos are well characterized by a simple function: $M(a) = M_o e^{-\alpha z}$, $a = (1+z)^{-1}$. Fits to this equation are shown in Figure 1 (left) for representative individual halos. The single free parameter α can be related to a characteristic epoch for formation, a_c , defined as the expansion scale factor a when the logarithmic slope of the accretion rate, $d \log M / d \log a$, falls below some specified value, S ; the functional form implies $a_c = \alpha / S$. The same formation epoch can be defined equivalently for any “observing” epoch z_o of that halo, by replacing a by a/a_o , in which case $a_c = a_o \alpha / S$. Thus at any such observing redshift, with scalefactor

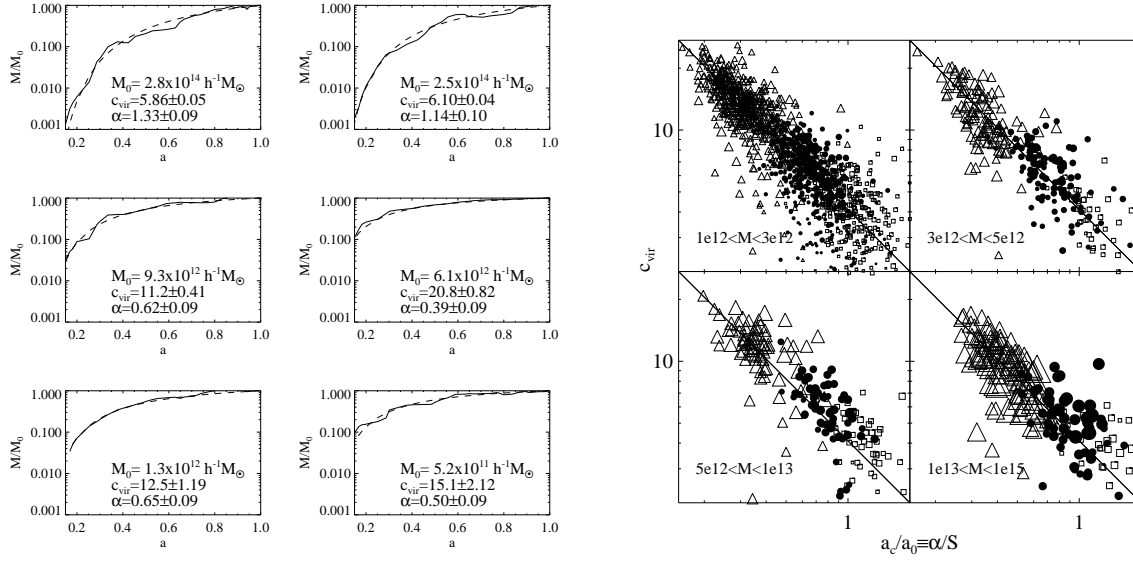


Figure 1: **Left:** Selected mass accretion trajectories, showing the evolution of the most massive progenitor for individual halos in the simulation (thick). Functional fits to the growth curve of each halo using Eq. 1 are shown as thin smooth lines. **Right:** Concentration versus scaled formation epoch a_c/a_0 , for halos at $z = 0$ (triangles), $z = 1$ (circles), and $z = 2$ (squares). The 4 panels correspond to different mass ranges. At all masses and redshifts, the concentration parameter c_{vir} is well fit by the functional form $c_{vir} = c_1 a_c/a_0$, where $c_1 \sim 4.1$ (represented by the solid line in each panel).

$a_0 = 1/(1 + z_o)$ and mass $M_0 = M(z_o)$, the mass growth is fit by

$$M(a) = M_0 \exp \left[-a_c S \left(\frac{a_0}{a} - 1 \right) \right]. \quad (1)$$

This implies that, for any halo whose mass accretion trajectory follows this functional form, the characteristic formation time is the same regardless of the redshift z_o at which the halo is observed.

We find that the concentration of a halo, defined as $c_{vir} \equiv R_{vir}/R_s$, is tightly correlated with the characteristic formation epoch as defined above, and that this relation holds at all redshifts when, properly scaled by a_0 :

$$c_{vir} = c_1 a_0/a_c, \quad (2)$$

where c_1 is the typical concentration of halos whose formation time is at the time of measurement, $a_c = a_0$. Figure 1 (right) shows that this formula provides a good description of the observed correlation between concentration and formation time for halos at all masses and redshifts. As mentioned, the typical formation time is a function of mass, but there is significant scatter in a_c for a fixed mass. The relation defined by Eq. 2 is able to account for the complete mass and redshift dependence of c_{vir} , and for the scatter in c_{vir} measured for fixed mass halos. This correlation has important consequences for galaxy formation modeling. For further details on this work, see [4].

References

- [1] Bullock, J. S., Kolatt, T. S., Sigad, Y., Somerville, R. S., Kravtsov, A. V., Klypin, A. A., Primack, J. R., & Dekel, A. 2001, MNRAS, 321, 559
- [2] Kravtsov, A. V., Klypin, A. A., & Khokhlov, A. M. 1997, ApJS, 111, 73
- [3] Navarro, J. F., Frenk, C. S., & White, S. D. M. 1996, ApJ, 462, 563
- [4] Wechsler, R. H., Bullock, J. S., Primack, J. R., Kravtsov, A. V., & Dekel, A. 2001, ApJ, in press, astro-ph/0108151